BIOPHYSICAL AND PHYSIOLOGICAL EVALUATION OF ELECTRICALLY HEATED HANDWEAR

NAVY CLOTHING AND TEXTILE RESEARCH FACILITY

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Five different electrical heating configurations for use with the Navy's Extreme Cold Weather Mitten (NECWM) were studied to determine if tolerance times in cold weather operations could be extended.

Four electrical heating configurations were incorporated in the existing polyurethane liner; one configuration used an electrically heated glove from the United Kingdom (UK) Ministry of Defense instead of the existing liner. All five configurations were tested on a Thermal Hand and physiologically to determine thermal insulation and effectiveness in maintaining finger temperatures. The UK glove liner had the highest effective insulation and was the most effective in maintaining finger temperatures in the comfort zone (27-34^{O}C), followed by the Fingers/Palm/Dorsal (FPD) heating configuration. In the FPD configuration test, the fingers were <20^{O}C after 120 minutes. The NECWM test showed the finger temperatures to be <15^{O}C after only 40 minutes of cold exposure.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The Navy Clothing and Textile Research Facility (NCTRF) studied different electrical heating configurations for use with the Navy's cold-wet mitten (MIL-M-87033) to determine if tolerance times for personnel performing watchstander duties during cold weather operations could be significantly extended. The study included both biophysical, Thermal Hand (TH) and physiological evaluations of the different heating configurations.

Five (5) configurations were employed with the neoprene outer shell of the mitten. Four (4) of the configurations incorporated electrical heating circuits with the polyurethane (PU) foam liner normally used in the mitten. The fifth configuration was an electrically heated knitted glove liner. This glove is employed by the United Kingdom (UK) Ministry of Defence (MOD) for its missile operators and vehicle crewmen. A direct current (DC) source was used to power the circuits. The voltages employed for the PU foam and knitted glove liners were 3 and 28 volts (V), respectively.

The TH evaluations was conducted using an average hand surface temperature of 34°C (93°F) with ambient temperatures of -10°C (14°F) and -25°C (-13°F), with a windspeed of approximately 8.7 knots (10 mph). The physiological evaluation was conducted in an ambient environment of -6.7°C (20°F), with a windspeed of 8.7 knots (10 mph).

The findings of this evaluation were as follows:

1. The UK electrical heating configuration was the most effective in heating the fingers and maintaining the finger temperatures in the comfort zone (27-34°C), or somewhat higher (39-41°C), during the cold exposure period.

2. The FPD electrical heating configuration requires a greater concentration of electrical heating wires in the finger regions to provide suitable warmth to the fingers. The finger temperatures dropped to and slightly below the discomfort level (<20°C) after 120 minutes of cold exposure.

3. The current cold-wet mitten was used as the control in this study and performed poorly. Finger temperatures were below or at the performance degradation level (< 15°C) after only 40 minutes of cold exposure.

4. ETIR values measured on the TH were predictive of the general performance of the heating configurations to warm the fingers, as occurred in the physiological evaluation.

5. Power supplies used with the electrical heating circuits must have adjustable voltage inputs in their circuitry to prevent overheating of the skin and must be compatible with available shipboard logistic support.

INTRODUCTION (CONTINUED)

This report describes the test items and equipment used, the test methods and procedures employed, and presents and discusses the results obtained. Conclusions and recommendations are also provided.

DESCRIPTION OF TEST ITEMS

The Navy's cold-wet mitten consists of a supported neoprene dipped outer shell and a removable insulation liner. The liner is made of a nylon tricot knit, flame bonded to a PU open cell foam structure. The mitten has four (4) compartments for the hand digits. The thumb and index and middle finger have separate compartments, and the ring and little fingers are in the same compartment (Figure 1).

It is difficult, if not impossible, to maintain the hands at a comfortable skin temperature in the cold for extended periods of time by passive means. To be effective, handwear must provide some useful hand dexterity. However, to meet low temperature requirements, bulkier handwear is needed. Personnel involved in low work level (sedentary) activities, such as performed by watchstanders and lookouts on open ship decks, require even more insulation because of their low heat generation levels.

The use of active heating devices, such as electrical heating elements within the handwear, provides a means of focusing more heat energy into the hand area with little increase to the bulkiness of the handwear. To determine the potential effectiveness of using electrical heating devices with the Navy's cold-wet mitten the following configurations were evaluated with the neoprene outer shell layer of the Navy's mitten.

1. The PU foam insulation liner, normally used with the mitten, was modified by sewing electrical resistance heating wires to the inside of the liner in three (3) distinct regions to form three (3) independent circuits. The regions were the perimeter of the fingers and thumb, and the palm and dorsal areas (Figure 2). The heating wire was obtained from Widder Electric and was made of copper. The wire was spirally wound on a synthetic filament core, covered by a plastic insulation, and had a nominal resistance of 0.02 ohms/cm. Each region dissipated between 4.2 and 4.7 watts at 3V DC. The 3V potential was chosen to prevent the heater wire surface temperature from exceeding the threshold of pain, (44^{o}C (111^{o}F))[1]. The three (3) circuits were evaluated independently and with all three (3) combined in parallel (13.5 watts) to determine the relative benefit to be derived from each configuration.

DESCRIPTION OF TEST ITEMS (CONTINUED)

2. A UK MOD electrically heated knitted glove liner was used in lieu of the PU foam liner (Figure 3). The UK glove also had three (3) circuits in parallel and dissipated 18.3 watts at 28V DC. The heating element wires were stainless steel insulated with PTFE, and ran along the dorsal side of the fingers, over the finger tips, and back along the palm side of the hand. The total resistance of each glove was 41 ohms. The heating element wires are inserted between the glove yarns as the glove is being knitted.

DESCRIPTION OF TEST EQUIPMENT

1. **Thermal Hand.** The TH (Figure 4) is constructed of a cast aluminum skin surface attached to a precast epoxy-glass composite, and is representative of the size of a 75 percentile male's right hand. The hand has a total surface area of $0.079m^2$ which includes the palmar and dorsal side wrist regions. For the hand alone, the surface area is $0.047m^2$. The hand area is segmented into seven (7) regions: thumb, fingers, and the palm and dorsal regions. The TH's control and data acquisition system independently controls and measures the surface temperature in each region. The electrical power used in each region to maintain a constant surface temperature is also controlled and measured. From this information, the effective overall and regional ETIR values (CLO) of a test glove or mitten can be determined:

   ETIR (CLO) = 6.45 (SA) (Ts-Ta)/P

   where:

   6.45 = units constant
   SA = total or regional surface area, m^2
   Ts = mean total or regional surface temperature, ^oC
   Ta = ambient temperature, ^oC
   P = total or regional power, W

2. **Environmental Chambers.**

   A. Biophysical, TH Evaluation. This evaluation was conducted in a bench-top Envirotronics environmental chamber where air temperatures can be controlled between -40 and 177^oC (-40 and 350^oF). The windspeed in the chamber was approximately 8.7 knots (10 mph).

   B. Physiological Evaluation. This evaluation was conducted in a walk-in environmental chamber where air temperatures can be controlled between -57 and 21^oC (-70 and 70^oF) and windspeed between 0 and 34.8 knots (0 and 40 mph). This chamber can accommodate a relatively large number of human volunteers for each test sequence. For this study, six (6) volunteers were used.

TEST METHODS AND PROCEDURES

This section describes the test methods and procedures employed in the conduct of these evaluations. Abbreviated identification of the various glove configurations is shown below:

Configuration	Glove Designations
Navy Cold-Wet Mitten, Control	C
Electrically Heated PU Foam Mitten Liner Used With the Neoprene Outer Shell of the Cold-Wet Mitten:	
- Finger-Thumb Circuit	F
- Palmar Circuit	P
- Dorsal Circuit	D
- Finger-Thumb, Palmar, and Dorsal Circuit	FPD
Electrically Heated UK MOD Glove Liner Used With the Neoprene UK Outer Shell of the Cold-Wet Mitten	

Biophysical, TH Evaluation

Each of the handwear configurations were evaluated on the TH in the bench-top environmental chamber. The surface temperature of the TH was 34°C (94°F) for all configurations. The ambient temperature for the C, F, P, D, and FPD configurations was -10°C (14°F) and -25°C (-13°F) for the UK configurations. The windspeed was 8.7 knots (10 mph). A potential of 3V was used to power configurations F, P, D, and FPD; and 28V to power the UK configuration.

TH measurements included the surface temperature of each finger, the thumb, palm, and dorsal areas, and the electrical current and voltage level in each region of the TH. Regional and overall ETIR values were computed from these measurements by a computer controlled data acquisition system.

Each test was repeated three (3) times and the results averaged.

TEST METHODS AND PROCEDURES (CONTINUED)

Physiological Evaluation

Test design: Appropriate Medical Command regulations were fully adhered to regarding the use of human test volunteers. Six (6) physically fit males participated as test volunteers. Each was informed of the purpose, procedures, and risks of the study; and signed a statement of informed consent. The average age of the volunteers was 22 years; height, 175 cm. (68.8 in.); and weight, 79.2 kg. (174.5 lbs.). The environmental conditions were -6.7^{o}C (20^{o}F) with a windspeed of 8.7 knots (10 mph). Each cold exposure was four (4) hours, or until one of the predetermined end-point criteria described below was reached. During the four (4) hours, volunteers alternately sat for 20 minutes and walked on a level treadmill at 1.1 m/s (2.5 mph).

Each volunteer participated in six (6) cold exposures using the different configurations of the electrically heated PU mitten and UK glove liners with the neoprene outer shell of the cold-wet mitten, and using the standard cold-wet mitten as the control. All volunteers participated in each of the test conditions. The order of presentation of the different test items was randomized.

The different configurations were C, F, P, D, FPD, and UK as defined earlier in this section. The electrical circuits were powered with an adjustable voltage DC power supply. The voltage and current supplied to each circuit was monitored periodically throughout the duration of each test sequence to insure the heating elements were working properly. During all tests, the following Navy protective clothing items were also worn:

- Cotton Thermal Underwear
- Fire Resistant Utility Uniform
  - Long Sleeve Cotton Chambray Shirt
  - Cotton Denim Trousers
- Anti-Exposure Coverall with Hood
  - Neoprene Coated Nylon Outer Shell
  - PVC Closed Cell Foam Inner Liner
- Nomex Cold Weather Facemask
- Wool Watch Cap
- Wool Cushion Sole Socks
- Cold Weather Insulated Rubber Boots

TEST METHODS AND PROCEDURES (CONTINUED)

Measurements and Safety Criteria

Rectal temperature was measured using a thermistor inserted approximately 10 cm. (4 in.) beyond the anal sphincter. Skin temperatures were measured using copper constantan thermocouples attached to the following twelve (12) sites: the lateral tips of the right thumb, right and left index fingers, right and left little fingers, and big toe of each foot; at the tip of the nose, the upper arm and forearm, and the upper chest and back.

Rectal and skin temperatures measurements were printed every two (2) minutes using a computer controlled data acquisition system. The electrocardiogram was obtained from chest electrodes (CM5 placement) and displayed on an oscilloscope and cardiotachometer unit. Each hour the metabolic rate was measured using open-circuit spirometry and the volunteers were asked to numerically rate their thermal sensations[2] using a nine-point temperature sensation scale ranging from -4 ("very cold") to a +4 ("very hot").

During any test, a volunteer was removed from the cold exposure if his rectal temperature decreased to 35°C (95°F), if his skin temperature at any site reached 4.5°C (40°F), or if he exhibited signs of impending cold injury or other unusual distress. A volunteer could also be removed at the discretion of the principal investigator or medical monitor, or could voluntarily withdraw at any time.

Statistical Analysis

The data were analyzed using analyses of variance for repeated measures. Thermal sensation data were analyzed using one-way analyses (test condition). All other data were analyzed using two-way analyses (test condition x time). The data points at times 20, 40, 60, 80, 100, and 120 minutes were used in the analyses. Tukey's test was used to determine results with significant differences. Significance was accepted at $p<0.05$.

RESULTS

Biophysical, TH Evaluation

The ETIR values for the different electrical heating configurations used with the outer shell of the Navy's cold-wet mitten (F, P, D, FPD, and UK) and the Navy's standard cold-wet mitten (C) are provided in Table I. Figure 5 shows the change in regional ETIR values compared to the standard cold-wet mitten for the different configurations.

RESULTS (CONTINUED)

The overall ETIR values (Table I), show that the FPD configuration had the highest value (2.47 CLO) and the UK configuration had the next highest value (2.16 CLO). The lowest overall value was C (1.34 CLO), but configurations F, P, and D were only slightly higher than C (1.61 CLO average).

The regional ETIR values (Table I and Figure 5), show that:

1. Configuration C had the lowest regional ETIR values for nearly all areas, with the lowest values being in the index and middle finger regions.

2. Configuration F provided limited improvement in ETIR values in the hand digit regions with a maximum increase of only 0.36 and 0.37 CLO compared to C in the thumb and little finger regions, respectively. Increases in all other regions were 0.25 CLO or less.

3. Configurations P and D provided little or no additional increase in ETIR values compared to C in the thumb, index, and middle finger regions. The largest increase in the hand digit regions by P when compared to C was 0.52 CLO in the little finger region. For configuration D, the increase in ETIR values compared to C was 0.31 and 0.38 CLO in the ring and little finger regions, respectively. In the palm region, configuration P increased the ETIR value compared to C substantially (1.6 CLO), while configuration D provided no improvement in this region. In the dorsal region, D increased the ETIR value compared to C by 2.78 CLO, with limited increase in ETIR value (0.21 CLO) provided by P in this region.

4. Configuration FPD provided similar increases in ETIR values as F in the thumb and middle finger regions when compared to C; and higher ETIR values than F, 0.12, 0.49, and 2.39 CLO, respectively, in the index, ring, and little finger regions. In the palm region, the FPD configuration increased the ETIR value when compared to P by 0.92 CLO, and increased the ETIR value in the dorsal area by 0.84 CLO when compared to D.

5. The UK configuration provided significant increases in ETIR values when compared to C in the thumb, middle, and ring finger regions (1.11, 0.42, and 0.74 CLO higher than FPD in these regions); was equivalent to FPD with respect to increases in ETIR values in the index and little finger regions; and had substantially lower increases in ETIR values compared to FPD in the palm and dorsal regions.

RESULTS (CONTINUED)

Physiological Evaluation

Exposure Time: The maximal duration of each cold exposure was limited to 240 minutes. Of the 36 tests conducted (six (6) volunteers x six (6) tests each), seven (7) were terminated early. In all but one case, the volunteers opted out of the test. For the case where the volunteer was removed from further testing, he wore configuration C. The time and finger temperature at termination were 126 minutes and 5.2°C. For three (3) of the remaining cases, the volunteers wore configuration C and the times and finger temperatures at termination ranged from 104-138 minutes, and 5.7-7.0°C, respectively. For the three (3) remaining cases, the volunteers wore configurations D, F, and FPD. In the tests with D and F, volunteers opted out at times and temperatures of 169 minutes and 7°C and 152 minutes of 8°C, respectively. In the test with FPD, the volunteer opted out at 180 minutes because of cold feet.

Rectal Temperature: There were no significant differences in the rectal temperature responses among the six (6) test conditions ($p > 0.05$). For test periods between 20 and 120 minutes for all configurations, the average rectal temperature was essentially constant (increased by 0.17°C, Figure 6).

Finger Temperature: Figures 7-11 show the reduction in hand digit temperatures for test periods between 20 and 120 minutes for the different mitten configurations. Also shown are the comfort, discomfort, performance degradation, and tolerance temperature levels; 27-34, <20, <15, and 5°C, respectively[3]. Table II shows the monitored hand digit temperatures at 120 minutes and their standard deviations and Table III shows all the statistically significant results for the different configurations and cold exposure periods. These results are detailed below:

UK - For all hand digits monitored; right thumb, right and left index fingers, and right and left little fingers; thermal equilibrium was maintained except for minor reductions in the right and left index finger temperatures, 2.6 and 3.5°C at 120 minutes, respectively. These temperatures, 26.5 and 29.3°C, were still near and above the lower comfort level (27°C). The right and left little finger temperatures, 40.7 and 39.8°C, respectively, exceeded the comfort zone (34°C). The performance of the UK configuration, with respect to the finger temperature level maintained, was substantially and statistically better than all other configurations (Table III).

RESULTS (CONTINUED)

FPD and P - For the thumb and index fingers the temperatures losses ranged from 16.1-19.0°C at 120 minutes, and were between the discomfort and performance degradation levels. For the little fingers the temperatures losses ranged between 19.9 and 21.3°C at 120 minutes, being at and slightly above the discomfort level. For the time periods where the performance of configurations FPD and P were statistically better than configurations F, D, and C see Table III.

F, D, and C - For these configurations, the temperatures of the monitored hand digits at 120 minutes were below the performance degradation level. The C configuration temperatures were the lowest. The only statistical temperature difference between these configurations was when D was compared to C at 40 minutes (Table III).

Upper Chest and Back Temperatures: The average temperatures for the chest and back were 30.2 and 29.6°C, respectively.

Oxygen Consumption: Average oxygen consumption measured during rest for all test conditions was 0.3 liters per minute.

Heart Rate: Average heart rates during rest for all test conditions were 69 and 66 beats per minute at 49 and 109 minutes, respectively.

Thermal Sensation: Thermal sensation responses by test volunteers for the different mitten configurations (Table IV) showed that the UK configuration provided substantially more effective heat to the hands than the other configurations. Sensation responses for the body and the hands were "neutral" to "hot" to "very hot", respectively, for the UK configuration. For the other electrical heating configurations, the responses for the body were "slightly cool", for FPD and F; and "cool" for P and D; while for the hands, the responses were "cool" for FPD and P; "cool to cold" for F; and "cold" for D. The responses to the control were "cold" for the body and "very cold" for the hands. The differences between the responses for the UK and the other configurations were significant ($p<0.05$) for both the body and the hands in all cases except for the FPD body condition. There were also significant differences between the FPD and C for both the body and the hands conditions, between F and C for the body condition, and between P and C for the hands condition. Sensation responses for the hands for the different configurations were essentially analagous to the hand digit temperature measurements at 120 minutes (colder sensations equated to lower finger temperatures, Table IV).

DISCUSSION OF RESULTS

Biophysical, TH Evaluation

All of the electrical heating configurations (F, P, D, FPD, and UK) provided higher ETIR values than C, as expected. Of these, the UK configuration had the highest or equivalent ETIR values compared to the other configurations in the hand digit regions. Compared to the remaining configurations, the FPD configuration performed best. The F configuration showed relatively small increases in ETIR values for all hand digit regions compared to C, while the P and D configurations provided little benefit with respect to increasing ETIR values in the hand digit regions (Table I, Figure 5).

Because the regions of the TH are thermally isolated from each other, there was little heat transfer (higher ETIR values) to the thumb, index, and middle fingers from configurations P and D or from the P and D areas of configuration FPD. These digits were also isolated by mitten design. For the ring and little finger, which were in the same mitten compartment, increases in ETIR values were greatest as a result of heat transfer from the P and D regions of the FPD configuration, 0.49 and 2.39 CLO, respectively (Table I).

With the limited distribution of heat to most of the finger regions from other heated regions for the FPD configuration, the density and distribution of the heating wires used in the finger regions needs to be increased if higher finger temperatures are to be achieved.

The differences in regional ETIR values between the various heating configurations indicate that UK configuration was more effective than the others in heating the hand digits when taken as a group, while the combination of configurations F, P, and D (FPD) was more effective in heating the palm and dorsal regions of the hand than the UK configuration.

Physiological Evaluation

For the test conditions employed in this evaluation, the human volunteers were in thermal equilibrium. This is evidenced in Figure 6 where the core (rectal) temperature remained stable, increasing slightly over time. After two (2) hours of exposure, average chest and back temperatures were 30.2 and 29.6^{o}C, respectively. Resting heart rates averaged 69 and 66 beats per minute at 49 and 109 minutes of exposure, respectively. Average oxygen consumption measured during rest was 0.3 liters per minute indicating that the volunteers were not shivering.

DISCUSSION OF RESULTS (CONTINUED)

Although the body remained in thermal equilibrium, reductions in finger temperatures varied, depending upon the electrical heating configuration employed. Table II shows average finger temperatures at 120 minutes of cold exposure for different configurations, and Figures 7-11 show the reductions in finger temperatures with time for the different configurations. From these data, it is obvious that the UK configuration was superior to the others with respect to the amount of heat it provided to the finger regions. At 120 minutes of exposure, the hand digit temperatures were significantly higher than with the other configurations (Table III), and essentially in the comfort zone (27-34^oC) for the right thumb and the right and left index fingers. For the right and left little fingers, the temperatures exceeded the comfort zone with maximum average temperatures of 40.7 and 39.8^oC, respectively. There were several occasions during the testing where the voltage to the UK configuration had to be reduced because the volunteers felt their fingers were becoming too hot (Table IV). The UK configuration requires an adjustable voltage control device as part of its circuitry to prevent overheating and potential burning of the skin.

For the FPD and P configurations, average finger temperatures at 120 minutes were between the discomfort and performance degradation thresholds (<20 and $<15^oC$, respectively) for the right thumb and the right and left index fingers, and essentially at the discomfort level for the right and left little fingers. The performance of the P configuration was suspect, however, because the investigator noticed that the volunteers were forming their hands into a fist to press their finger tips against the palmar circuit (P) to take advantage of the heat energy available in this area. The influence of the hand position on performance is further reinforced when the finger temperatures achieved with the P configuration (Table II) are compared to their ETIR values (Table I).

For the F, D, and C configurations, average finger temperatures at 120 minutes were between the performance degradation and tolerance levels (<15 and 5^oC, respectively) for all hand digits measured.

The poor performance of the F configuration to adequately heat the fingers also affected the performance of the FPD configuration since it was also dependant on the F circuit to heat the fingers. These results with human volunteers also indicate as did the TH results the need for a greater concentration and distribution of electrical heating wires over the finger regions with the FPD configuration to provide adequate heat energy to these regions.

Thermal sensation responses from the volunteers for each configuration regarding the hands were analogous with finger temperature measurements for that configuration (Tables IV and V), indicating that measured temperatures were accurate and reflective of the conditions present and not due to contact of thermocouples with heating wires of some other abberation.

DISCUSSION OF RESULTS (CONTINUED)

Comparison of TH ETIR Values and Physiological Evaluation Finger Temperature Results

The ETIR results (Table I) and the finger temperature measurements at 120 minutes (Table II) indicate that the ETIR results were predictive of the general performance of the heating configurations to warm the fingers, except for the P configuration as discussed earlier, where in either evaluation the UK configuration would have been chosen best and the C configuration worst, with the FPD, F, and D configurations ranked between these two (2) configurations in the order shown. However, because of the way the hand was exposed to the environment in the physiological evaluation with the P configuration (volunteers forming a fist to take advantage of the palmar circuit heat), the P configuration would be ranked equivalent to the FPD configuration, whereas in the TH evaluation the P configuration was ranked equivalent to the D configuration.

Logistic Support

A lightweight and compact portable power supply is needed to power the electrical circuits. The UK configuration requires a 28V DC source with an adjustable input voltage to prevent overheating of the skin. A redesigned FPD configuration that provides sufficient heating to the fingers may require more than the 3V DC source used in this study to power its circuitry. Whatever the required input voltage the FPD source should also have an adjustable input voltage to prevent overheating of the skin. The power supply must also be compatible with available shipboard electrical equipment if it is rechargeable, or compatible with shipboard disposal procedures if the power source is not rechargeable and is to be discarded.

Current Cold-Wet Mitten

The passive cold weather protection provided by the current mitten, configuration C in this study, needs to be improved. From Figures 7-11 it can be seen that finger temperatures were below or at the performance degradation limit ($<15^oC$) after only 40 minutes of cold exposure. Some of the newer fibrous insulation materials such as Thinsulate should be investigated as potential replacements for the current polyurethane foam liner.

CONCLUSIONS

1. The UK electrical heating configuration was the most effective in heating the fingers and maintaining the finger temperatures in the comfort zone (27-34°C) during the cold exposure period.

2. The FPD electrical heating configuration requires a greater concentration of electrical heating wires in the finger regions to provide suitable warmth to the fingers. The finger temperatures dropped to and slightly below the discomfort level (<20°C) after 120 minutes of cold exposure.

3. The current cold-wet mitten was used as the control in this study and performed poorly. Finger temperatures were below or at the performance degradation level (<15°C) after only 40 minutes of cold exposure.

4. ETIR values measured on the Thermal Hand were predictive of the general performance of the heating configurations to warm the fingers, as occurred in the physiological evaluation.

5. Power supplies used with the electrical heating circuits must have adjustable voltage inputs in their circuitry to prevent overheating of the skin, and must be compatible with available shipboard logistic support.

RECOMMENDATIONS

1. Implement the use of the UK glove configuration with the outer shell of the present cold-wet mitten providing a suitable portable adjustable power supply can be obtained or developed.

2. Redesign the FPD configuration to improve the warmth provided to the fingers and determine the availability or need to develop a suitable power supply.

3. Investigate some of the newer fibrous insulation materials as potential replacements for the polyurethane foam liner to improve the passive thermal protection of the current cold-wet mitten.

TABLE I. Regional and Overall Thermal Hand Effective Thermal Insulated Resistance (ETIR) Values (CLO) for Different Electrical Heating Configurations used with the Outer Shell of the Navy's Cold-Wet Mitten.

		----	----	Regional	ETIR	----	----	
Mitten Configuration	**Thumb**	**Index Finger**	**Middle Finger**	**Ring Finger**	**Little Finger**	**Palm**	**Dorsal**	**Overall ETIR**
C	1.40	0.84	0.96	1.56	1.40	1.48	1.68	1.34
F	1.76	1.09	1.19	1.77	1.77	1.72	1.83	1.59
P	1.41	0.89	0.97	1.60	1.92	3.08	1.89	1.62
D	1.39	0.88	0.97	1.87	1.78	1.47	4.46	1.61
FPD	1.77	1.21	1.19	2.26	4.16	4.00	5.30	2.47
UK	2.88	1.19	1.61	3.00	4.23*	2.74	1.86	2.16

NOTES:

Temperature TH: 34°C (93°F)

Ambient Temperature:
F, P, D, and FPD -10°C (14°F)
UK -25°C (-13°F)

Windspeed: 8.7 Knots (10 MPH)

*Results from one test.

TABLE II. Finger Temperatures at 120 Minutes of Cold Exposure* for Different Cold-Wet Mitten Configurations.

	- - - - - - -	- - - - - - -	Hand	Digit (^oC)	- - - - - -
Mitten Configuration	Right Thumb	Right Index	Left Index	Right Little	Left Little
UK	33.4±5.6	26.5±6.8	29.3±9.6	40.7±4.8	39.8±2.8
FPD	16.3±4.6	19.1±6.4	19.0±4.8	21.2±5.5	21.3±4.8
P	16.1±4.9	17.4±5.1	18.6±6.7	19.9±6.0	20.4±7.2
F	14.2±1.8	13.1±1.6	11.9±2.1	13.1±1.5	13.9±3.1
D	12.8±2.4	11.6±4.5	11.9±3.6	14.0±4.0	12.2±1.6
C	10.0±3.4	9.3±4.8	8.7±3.9	9.3±2.3	9.6±3.9

Legend
- UK - Electrically Heated Knitted Glove Insert
- FPD - Electrically Heated Mitten Insert, Fingers, Palm, and Dorsal Areas
- P - Electrically Heated Mitten Insert, Palm Area
- F - Electrically Heated Mitten Insert, Finger Area
- D - Electrically Heated Mitten Insert, Dorsal Area
- C - Navy Cold-Wet Mitten, Neoprene Outer Shell, Polyurethane Foam Insert

* -6.7°C, 8.7 Knots (10 MPH)

TABLE III. Statistically Significant ($p<0.05$) Results for Different Cold-Wet Mitten Configurations and Cold Exposure* Periods.

Hand Digit	*NCWM* Configuration	*Time (minutes)* 20	40	60	80	100	120
Right	UK>	All	All	All	All	All	All
Thumb	FPD>		C	C	C	C	
					D		
	P>				C		
Right	UK>	All	All	All	All	All	All
Index	FPD>	C	C	C	C	C	C
Finger							
	P>	C	C	C	C	C	C
Left	UK>	All	All	All	All	All	All
Index	FPD>			C		C	C
Finger				D		D	
						F	
	P>		C	C		C	C
						D	
						F	
Left	UK>	All	All	All	All	All	All
Little	FPD>		C	C	C	C	C
Finger					D	D	D
			F	F	F	F	F
	P>	C	C	C	C	C	C
				D	D	D	D
		F	F	F	F	F	F
Right	UK>	All	All	All	All	All	All
Little	FPD>		C	C	C	C	C
Finger				D	D	D	D
				F	F	F	F
	P>	C	C	C	C	C	C
					D	D	
							F
	D>		C				

Legend
- NCWM - Navy Cold-Wet Mitten, Neoprene Outer Shell, Polyurethane Foam Insert
- UK - Electrically Heated Knitted Glove Insert
- FPD - Electrically Heated Mitten Insert, Fingers, Palm, and Dorsal Areas
- P - Electrically Heated Mitten Insert, Palm Area
- D - Electrically Heated Mitten Insert, Dorsal Area
- F - Electrically Heated Mitten Insert, Finger Area
- C - NCWM, Control

* $-6.7^{o}C$, 8.7 Knots (10 MPH)

TABLE IV. Thermal Sensation Responses to Cold Exposure* for Different Electrical Heating Configurations and the Navy's Cold Wet-Mitten.

	------- Thermal		Sensation ------	
Mitten Configuration	Body	Scale	Hands	Scale
UK	0.0±0.6	Neutral	3.5±0.8	Hot to Very Hot
FPD	-1.2±0.8	Slightly Cool	-2.3±1.6	Cool
P	-1.7±0.5	Cool	-2.2±0.8	Cool
F	-1.3±1.0	Slightly Cool	-2.5±1.0	Cool to Cold
D	-1.7±1.2	Cool	-2.7±1.2	Cold
C	-2.7±0.9	Cold	-4.2±0.4	Very Cold

Significance ($p<0.05$)

Body
- UK> P, F, D, and C
- FPD> C
- F> C

Hands
- UK> FPD, P, F, D, and C
- FPD> C
- P> C

* -6.7°C, 8.7 Knots (10 MPH)

TABLE V. Comparison of Hand Thermal Sensation Responses to Hand Digit Temperatures at 120 Minutes for Different Electrical Heating Configurations and the Navy's Cold-Wet Mitten.

Mitten Configuration	Thermal Sensation Response	Finger Temperature Range (^{o}C)
UK	Hot to Very Hot	26.5 to 40.7
FPD	Cool	16.3 to 21.3
P	Cool	16.1 to 20.4
F	Cool to Cold	11.9 to 14.2
D	Cold	11.6 to 14.0
C	Very Cold	8.7 to 10.0

Figure 1. U.S. Navy's Cold-Wet Mitten

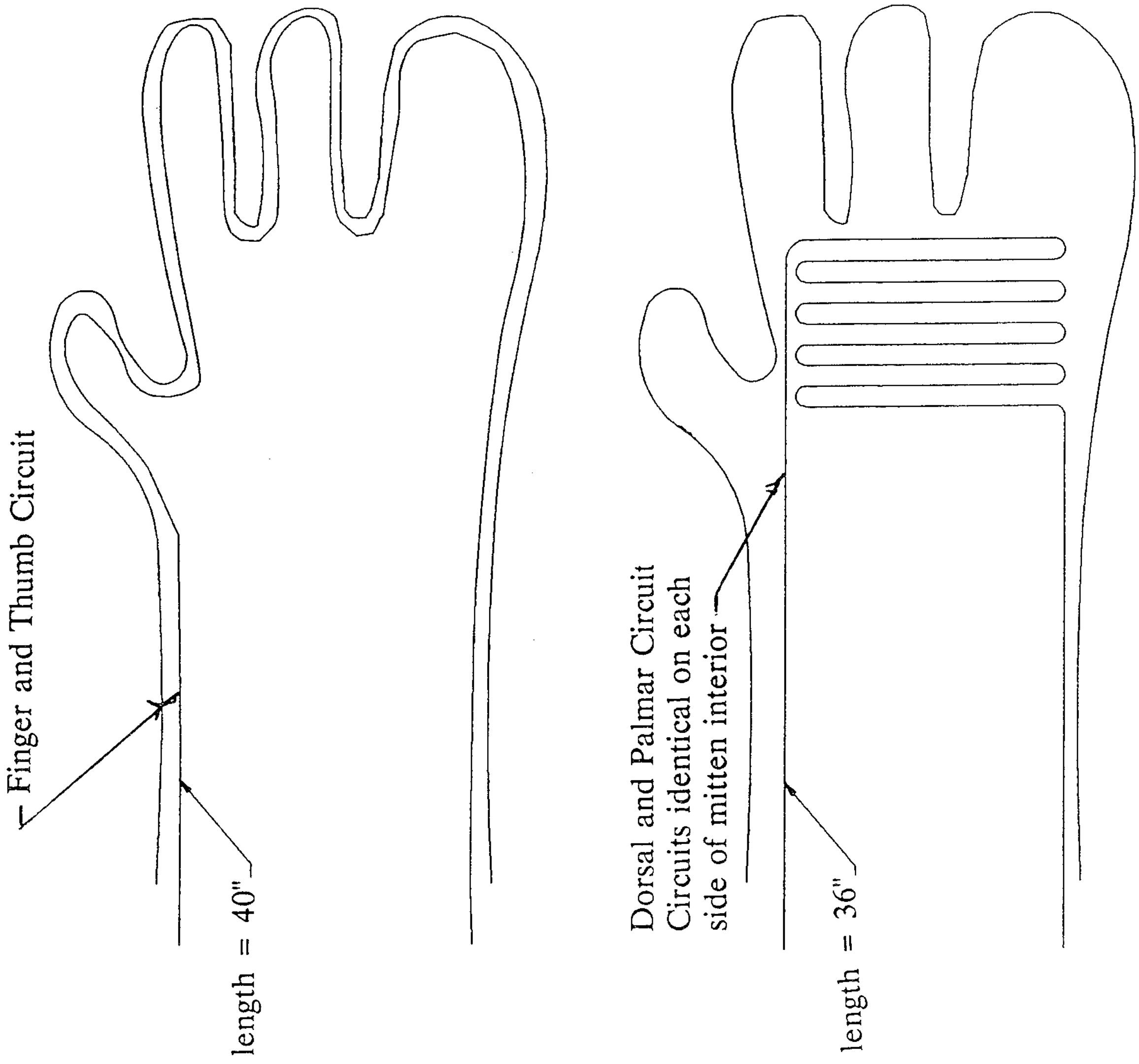

Figure 2. Diagram of the Electrical Resistance Heating Circuits Sewn to the Inside of the Polyurethane Foam Insulation Liner of the Navy's Cold-Wet Mitten

Figure 3. UK, Ministry of Defence Electrically Heated Knitted Glove Insert

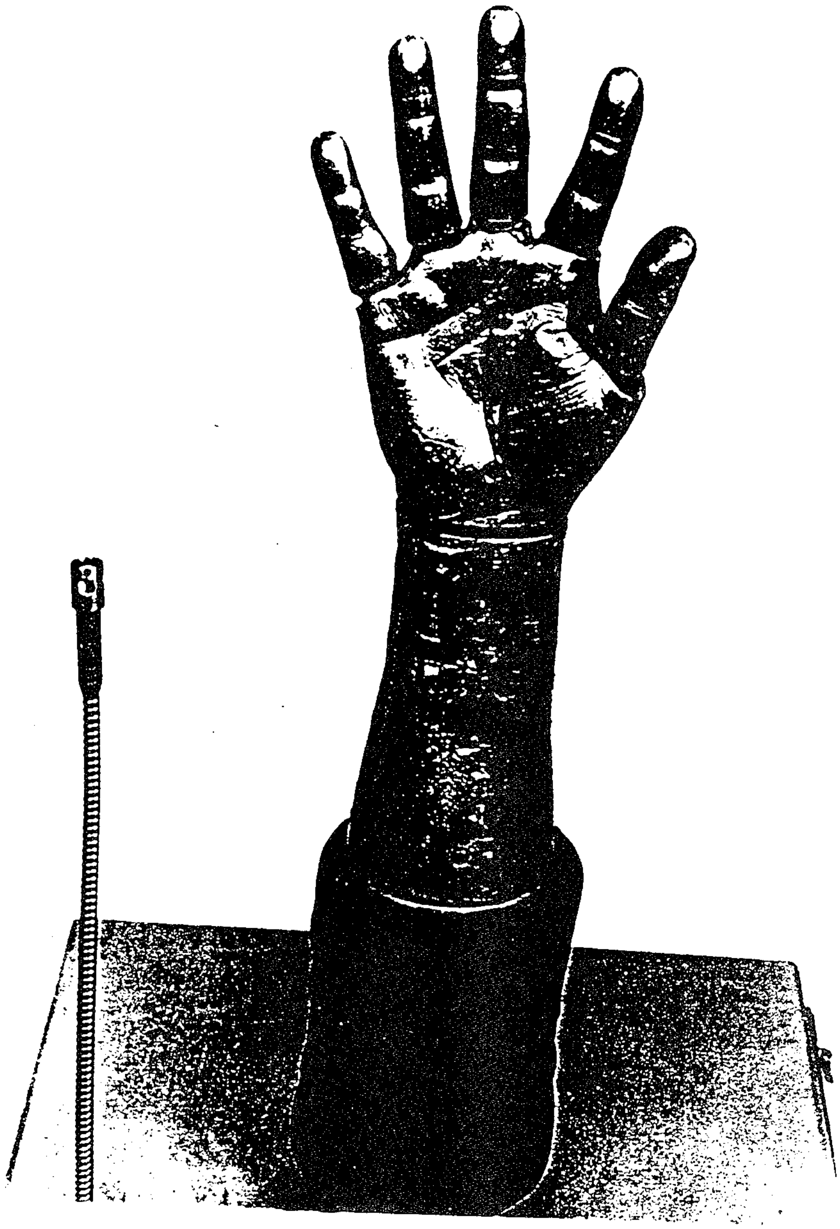

Figure 4. Thermal Hand used to Measure Regional and Overall Effective Thermal Insulation Resistance (ETIR) Values (CLO)

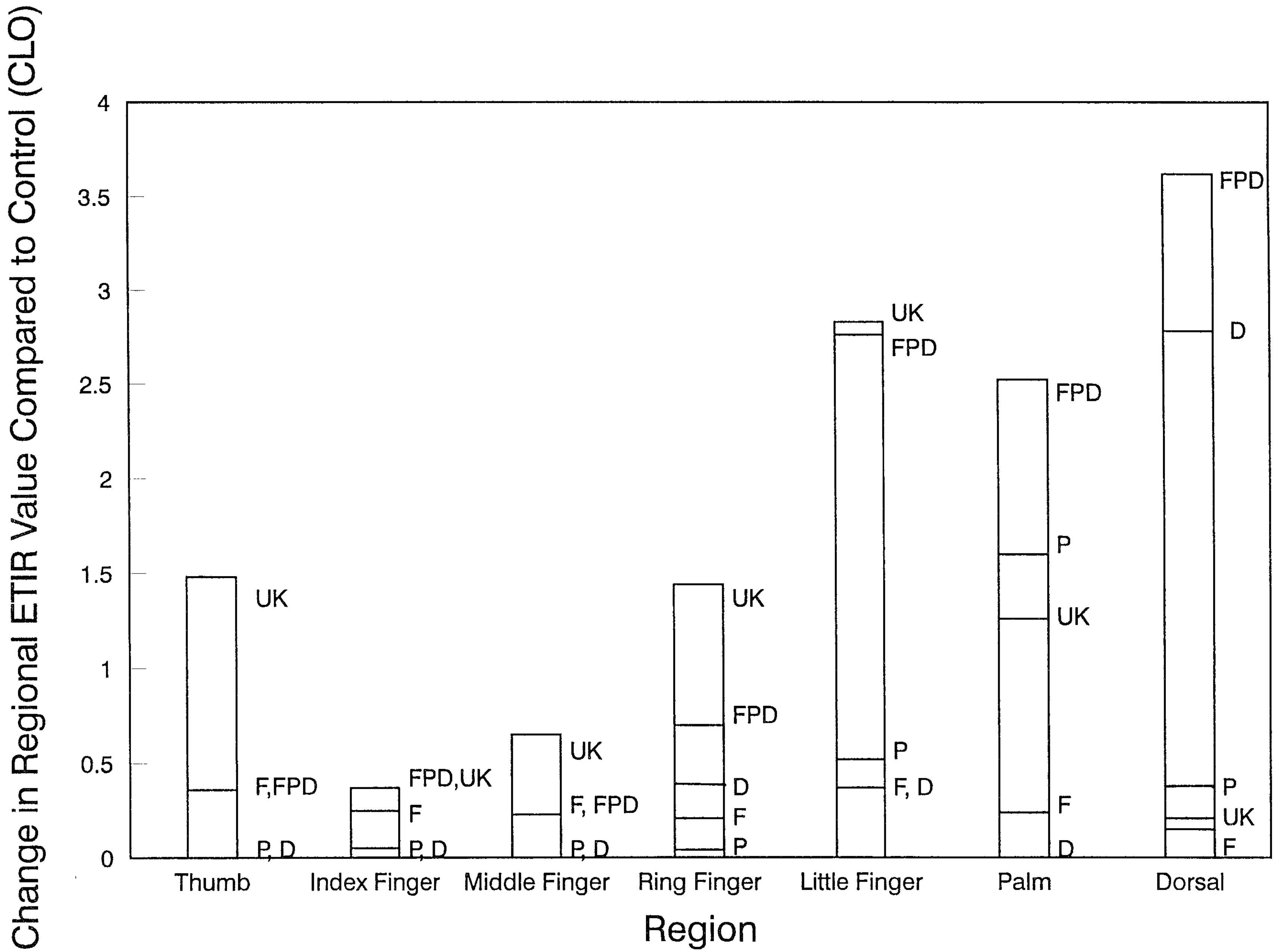

Fig. 5 Change in Regional Effective Thermal Insulation Resistance (ETIR) Values (CLO) Compared to Control for Different Electrical Heating Configurations Used with the Outer Shell of the Navy's Cold-Wet Mitten

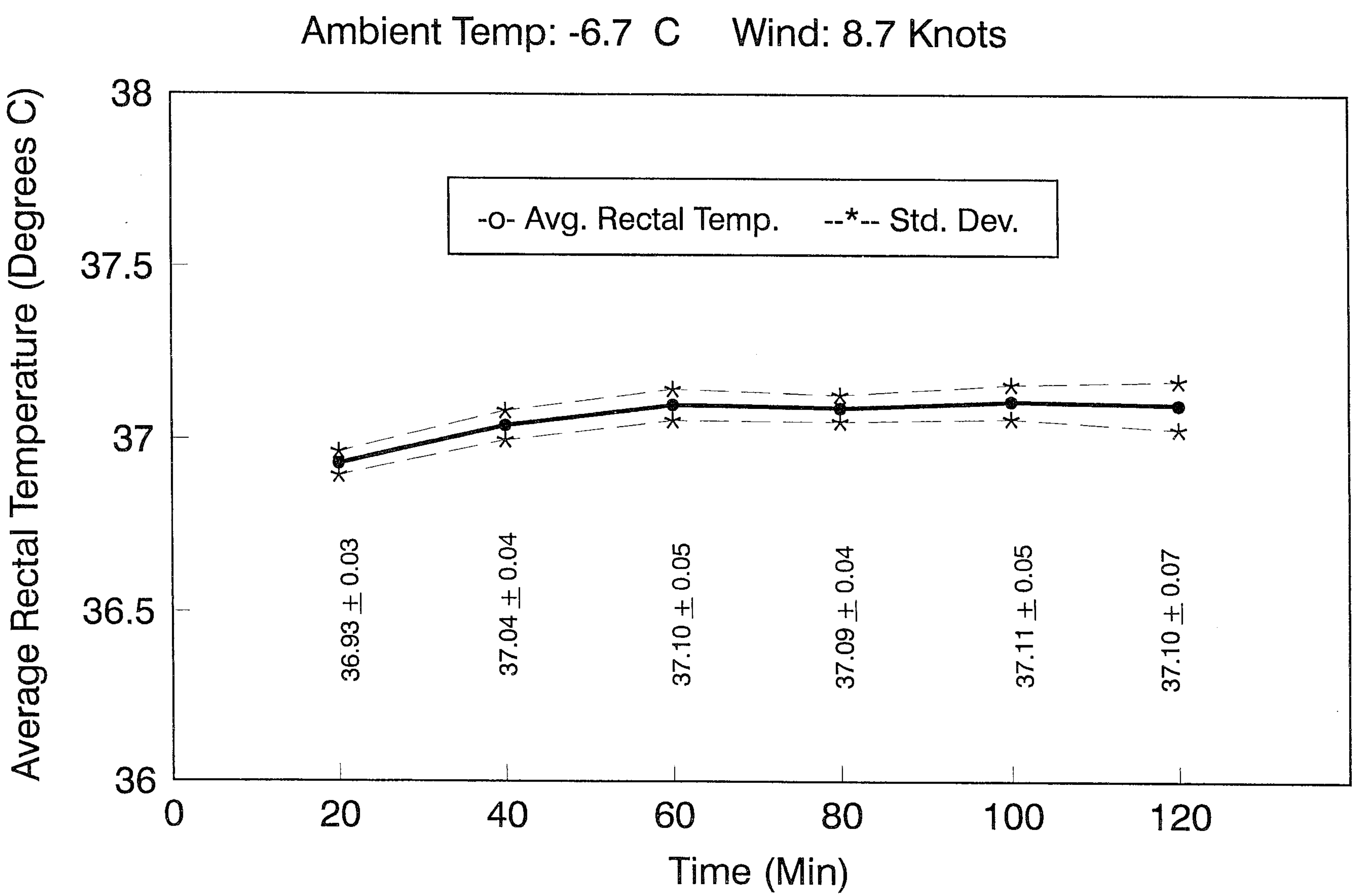

Fig. 6 Average Rectal Temperature Versus Time for Different Electrical Heating Configurations and the Navy's Cold-Wet Mitten

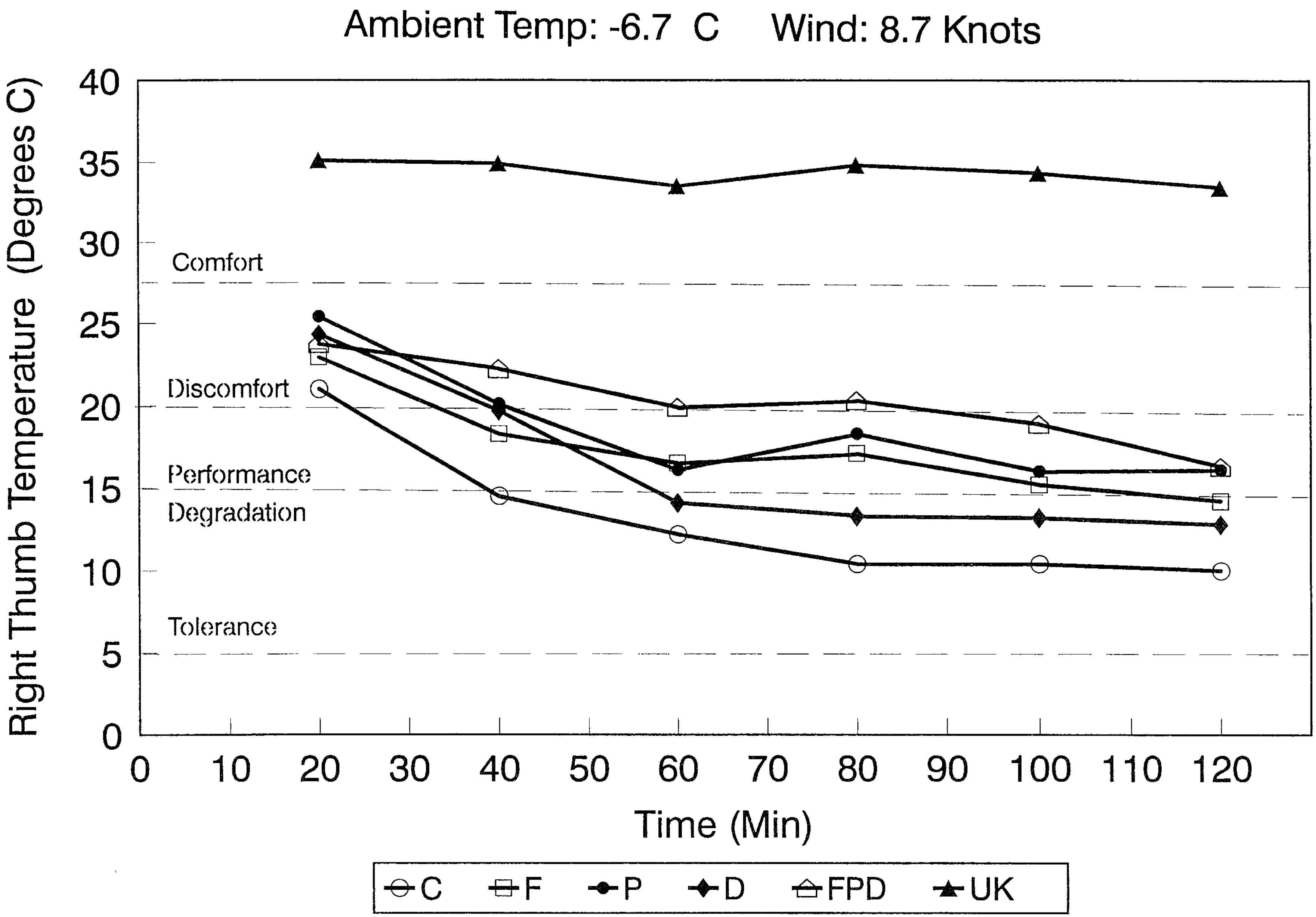

Fig. 7 Right Thumb Temperature Versus Time for Different Electrical Heating Configurations and the Navy's Cold-Wet Mitten

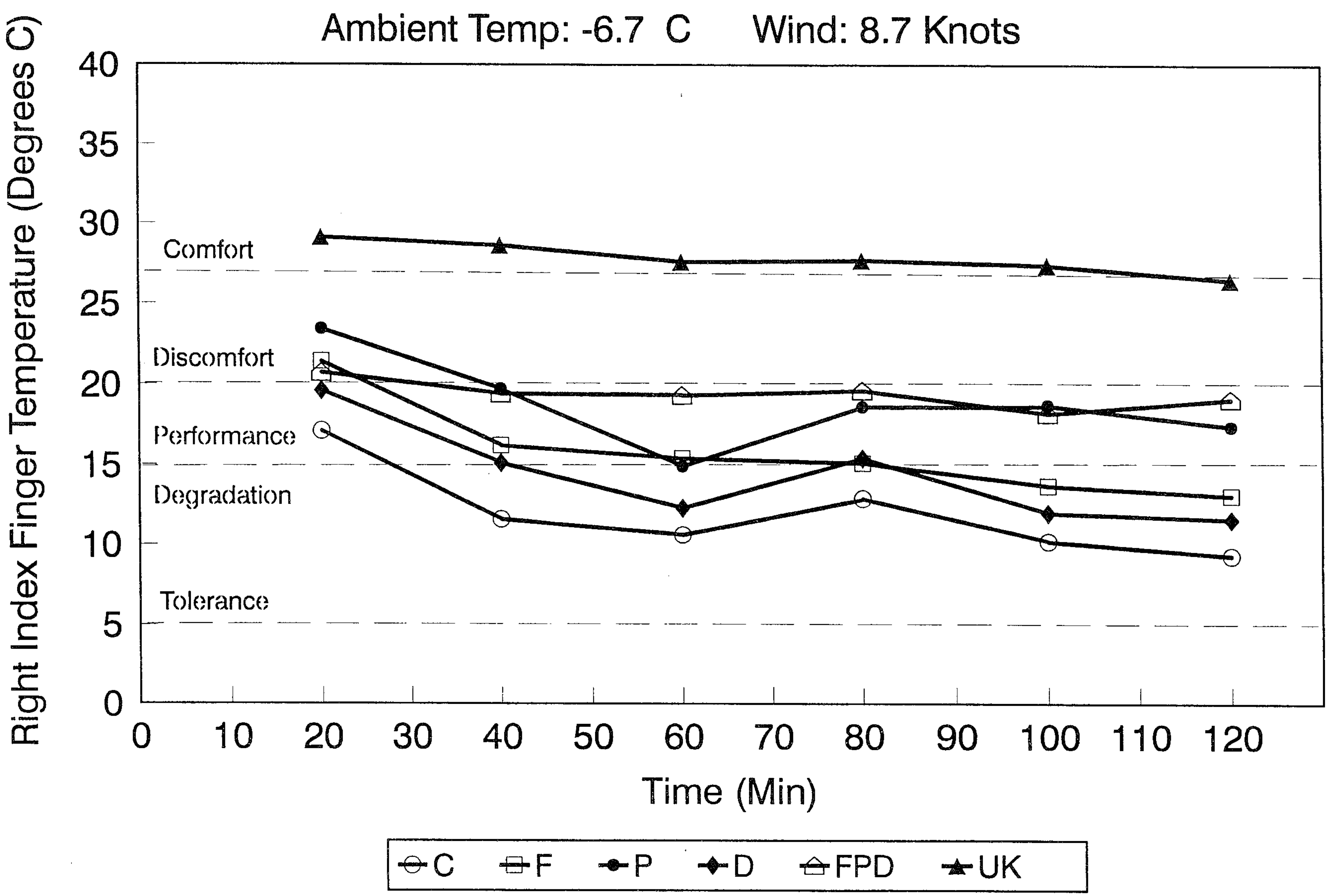

Fig. 8 Right Index Finger Temperature Versus Time for Different Electrical Heating Configurations and the Navy's Cold-Wet Mittens

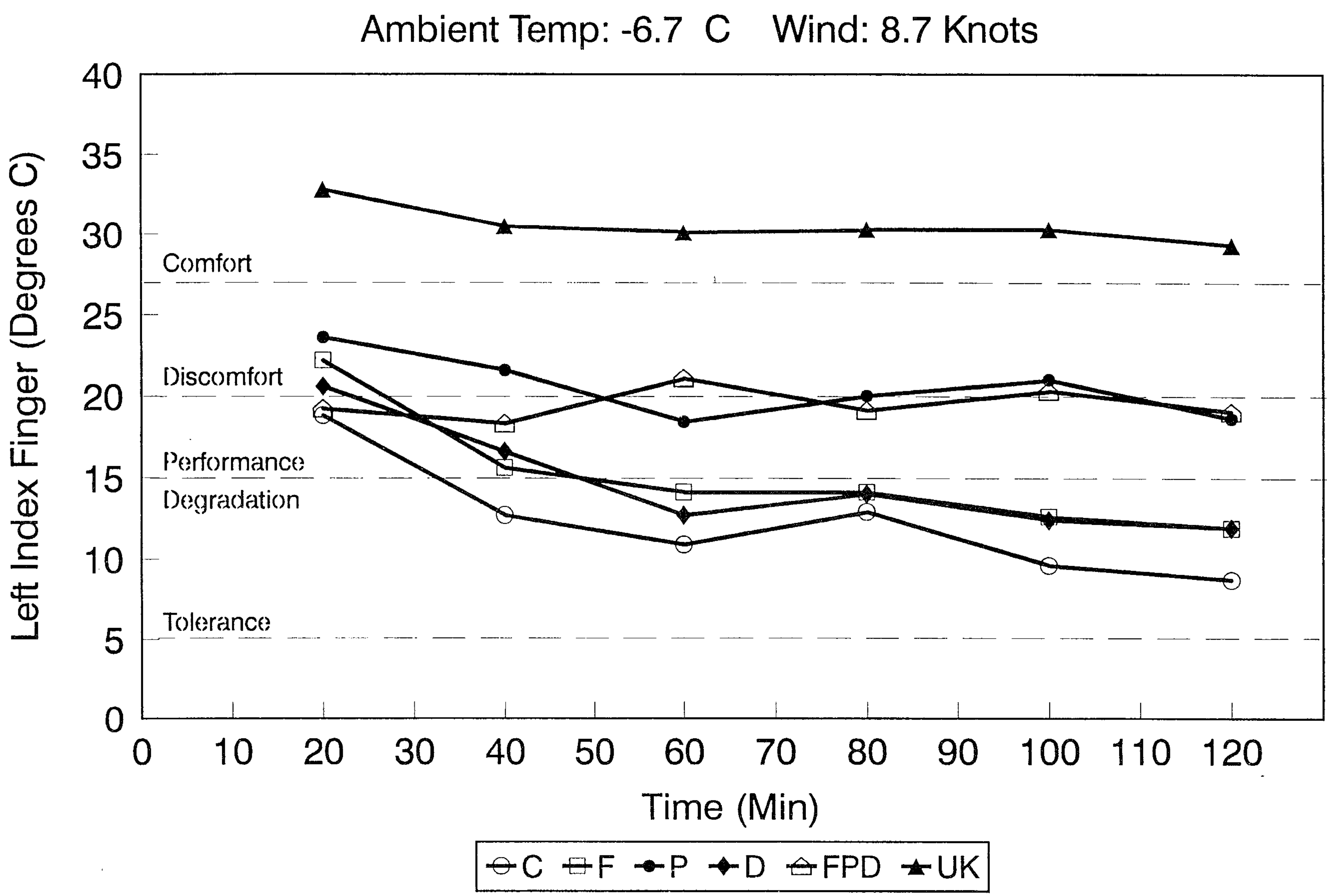

Fig. 9 Left Index Finger Temperature Versus Time for Different Electrical Heating Configurations with the Navy's Cold-Wet Mitten

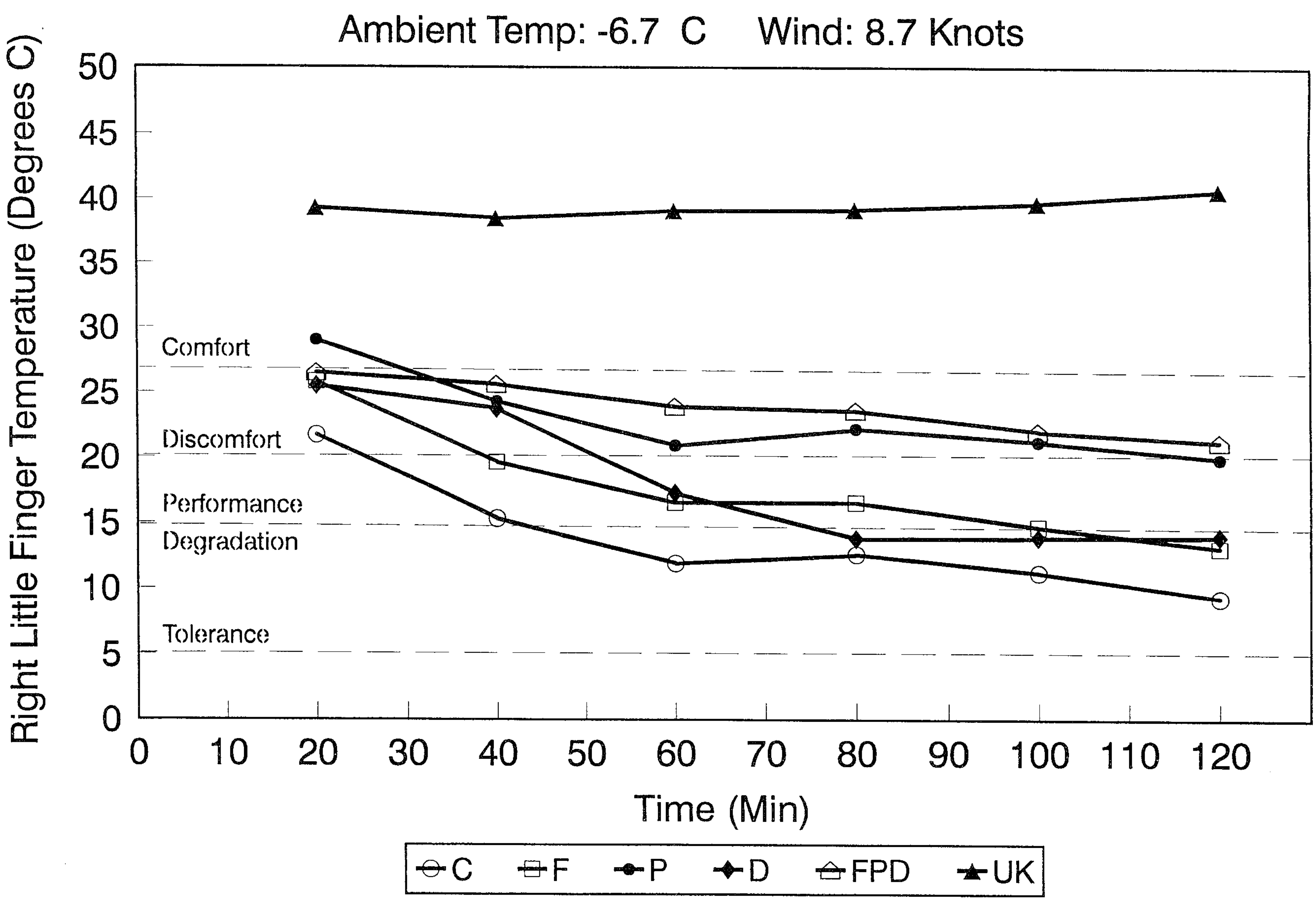

Fig. 10 Right Little Finger Temperature Versus Time for Different Electrical Heating Configurations and the Navy's Cold-Wet Mitten

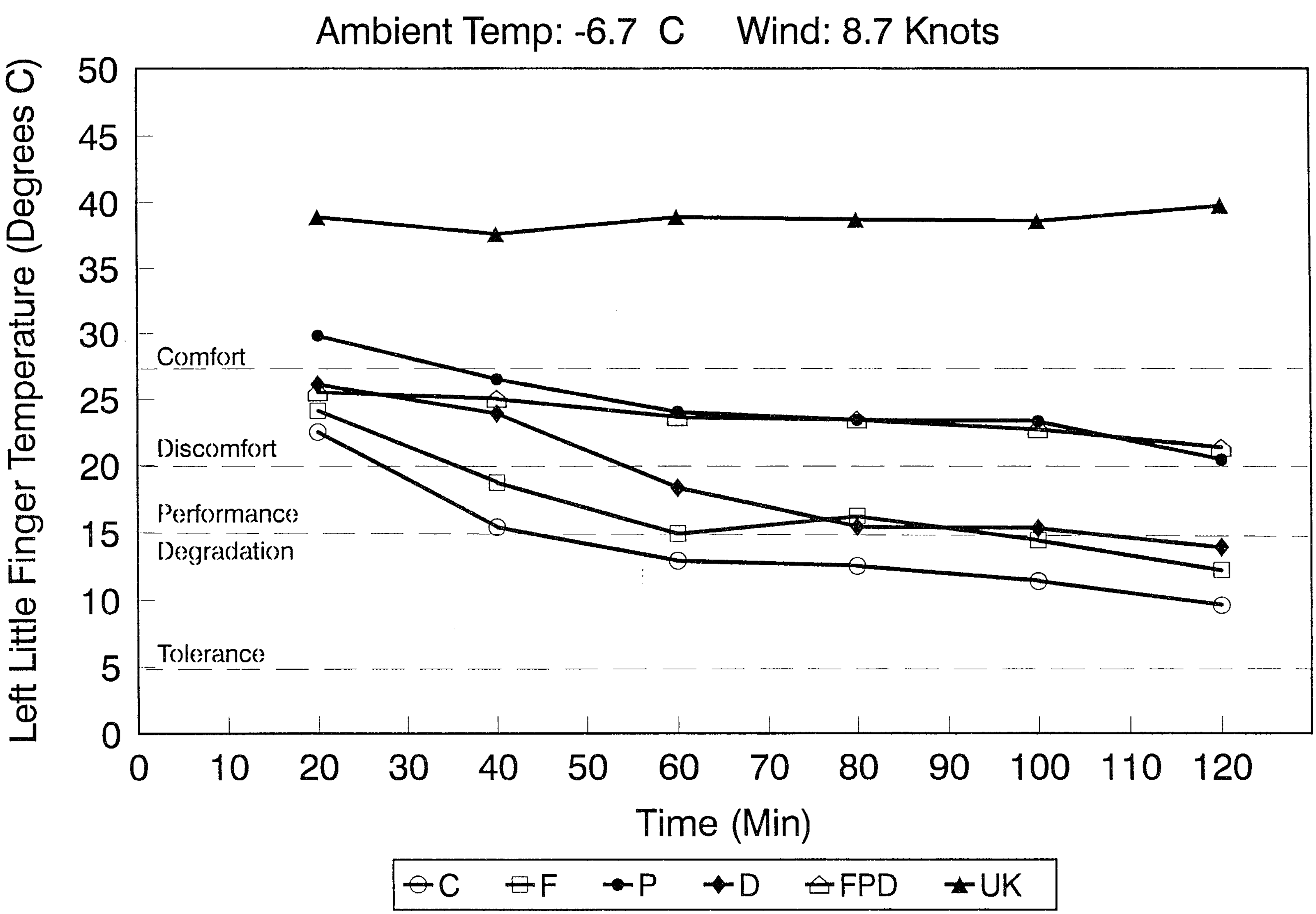

Fig. 11 Left Little Finger Temperature Versus Time for Different Electrical Heating Configurations and the Navy's Cold-Wet Mitten

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